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Ways of promoting the soil fauna diversity and the soil biomass in tropical regions

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INTRODUCTION 225
MANAGEMENT PRACTICES STIMULATING SOIL FAUNA 225
PERFORMANCE OF THE SOIL FAUNA IN DIFFERENT ECOSYSTEMS 227
APPLICATION OF CHEMICALS AND FIRE 228
CONCLUSIONS 231
REFERENCES 231

INTRODUCTION

The soil is a biological ecosystem that has and generates life and all living beings, no matter how small or unsignificant has its role in the life cycle. In the soil there are millions of organisms per m^2 which are divided in macro and mesofauna and microorganisms. The mesofauna is composed of protozoans, nematodes, acarus and collembola; the macrofauna by centipedes, termites, insect larvae, worms and molluscs. The microorganisms are composed of actinomycetes, fungi, bacteria and algae (Lavelle 1983).

The weight of animals living in the soil is of approximately 0.21% of the agricultural soil. However, their importance is not in their number and weight, but in their role in all the biological cycles and their effect on its structure and fertility.

The factors participating in the soil also affect the fauna, thus, all labours applied for soil recovery contribute to the activation of this fauna.

The aim of this review is to analyse the possible ways of stimulating the activity of soil fauna for its use in tropical regions.

MANAGEMENT PRACTICES STIMULATING SOIL FAUNA

Among the main factors affecting the intensity of the soil fauna activity are:

- the method of soil preparation
- the application of organic matter
- strip crops
- crop rotation
- the use of plant coverage
- the type of crop
- crop intensity

In the past, developed countries from temperate climates considered that the soil had to be turned over, instead of loosening it. For this, they developed moldboard ploughs and later disc and harrow ploughs, which made production in cold soils possible. Later, these technologies were transferred to tropical regions, decreasing land productivity and creating deserts as those found in India, Africa and Brazil (Primavesi 1990).

The exposure of the soil to the sunshine is beneficial only for temperate soils, but this is frequently harmful for tropical soils, since the fauna and the volume of rooted soil are drastically reduced (Primavesi 1990). In the tropics, excess tillage intensifies organic matter oxidation, buries the most active parts of the soil and favours erosion.

Frequently, intensive tillage reduces soil population of live organisms (Zelaya and Pitty 1995). Minimum tillage is now used world-wide and it consists of reducing soil labours only to those necessary and according to Silva and Razo (1990), they must be the best biological, economical and technological option possible, according to the area.

At 15 cm depth, in ploughed soils, it is estimated that there are from 30 to 300 worms per square meter, which represent between 110 to 1100 kg of liveweight per hectare. However, in soils without ecological disturbances there are 2000 to 30 000 worms per square meter (Zelaya and Pitty 1995).

Reduced tillage practices, increase the populations of microorganisms and worms on the soil surface (House and Parmele 1985, Parmele et al 1990). These latter authors found 70% more worms and biomass in the soils with this type of tillage.

Also, another very beneficial practice is being used for the soil fauna, consisting of leaving intercropped plant strips in the ploughed fields to produce, at the shortest possible term, a diverse soil recolonization, which serves as refuge to the wild macro and mesofauna communities. In Cuba, this technique has allowed to increase the microbial activity in eroded soils used for tobacco production in the Pinar del Río province (Suárez et al 1991).

Under optimum humidity and temperature, the soil could have a certain number of typical microorganisms. However, both the level and the composition could rapidly change, when the conditions vary. These changes could be due to drought, humidity, freezing and thawing, cold weather, hot weather and fumigation. In general, the level of microorganisms in the soil is positively correlated with the level of organic matter (Herns 1986).

According to Voisin (1962) with the incorporation of organic manure to the soil, the number of earthworms increases, from 609 to 701/m^2, which represents a slight increase of 15% besides offering new vigour to the earthworms with average weight varying from 296 to 336 g by increasing their biomass in 13% This brings about a 29% increase of the total biomass per hectare on increasing their weight from 1 810 to 2 325 kg.

Cellulosic material such as straw, crop residues, sugar cane, bagasse, coffeee hulls etc must be periodically incorporated to the soil to supply the bacteria with a feeding source rich in structural carbohydrates for the production of polyuronic acids which, in turn, serve as feed for the fungi which, through their hyphas, cover and pack the soil forming cluster giving the soil its structure. When the acids are exhausted, the fungi hyphas die and the clusters lose their stability.

On the other hand, practices used for crop production negatively or positively affect populations of pests or beneficial organisms. Crop rotation is an efficient method for pest and disease control and the conservation of soil productivity (Buckman and Brady 1962). This is not an arbitrary change in crops and it must be used to establish a biological equilibrium which has been weakened or destroyed by monoculture.

It is well-known that soil productivity and crop health decrease drastically in monoculture systems and that its conservation will be difficult. However, in a polyculture system with rotation these problems are strongly reduced.

On the other hand, there are different types of coverage: living or dead plants, plastics, etc and the use of one or the other depends on its purpose and the season. There are advantages and disadvantages in their use Artificial coverage avoids water evaporation and decreases the influence of sun's rays, but it has the disadvantage that it does not allow water infiltration and making no contribution to the soil.

Dead plant coverage, besides protecting the soil from erosion creates a typical microclimate in the upper layer by decreasing the incidence of the sun's rays, the

TABLE 1. Labour practices positively affecting soil fauna

	Benefic organisms	Country	Author
Minimum tillage	Microorganisms	Cuba	Suárez et al (1991)
Intercropping	Earthworms	Nigeria	Hauser (1993)
	Earthworms	USA	Hendrix et al (1992)
Crop rotation	Microorganisms	México	González and Ferrera (1994)
	Microorganisms	Germany	Kaiser and Himeyer (1993)
Application of organic matter	Microorganisms	France	Houot and Chaussod (1995)
Direct sowing	Microorganisms	France	Brussaard and Faasen (1994)
Coverages	Earthworms	Nigeria	Atta-Krah and Kang (1993), Tian et al (1993)
	Earthworms	Nigeria	Lal et al (1980)
	Earthworms	Africa	Lavelle et al (1991)
	Earthworms	Nigeria	Brussaard and Fasen (1994)
Green manure	Earthworms	Brazil	Promavesi (1990)
	Earthworms	Nigeria	Tian et al (1993)
	Collembola	Germany	Filser (1995)

temperature and increasing soil humidity and it nurishes the microorganisms, finally, conserving soil biostructure (Lal 1974, Lal et al 1980, Tian et al 1993). This type of coverage is widely used in the dry season, but in the rainy season the coverage with living plants must be used to avoid the erosive action of rainfall and leaching.

In a study carried out in Ibadan, it was found that the periodical incorporation to the soil of **Leucaena leucocephala** and **Gliricidia sepium** foliages showed good results, not only by increasing the nutritional status of the soil and its organic matter content (which was doubled), but it also produced a decrease in temperature of the surface layer and an increase of the biological activity, particularly of earthworms (Atta-Krah and Kang 1993). Tian et al (1993) conducted a similar study to evaluate this species as well as **Acioa barteri**, maize and rice straw. Results agree with those above and these authors also reported that the other species stimulated mainly the termites.

The live coverage is used to protect the soil through intercropped or in associations with the main crop. Its use is more frequent in crops that do not allow reduced distances between rows due to mechanization.

The protecting crops (live coverage) are very beneficial in the rainy season, but they must be used with caution in the dry season, where coverage with dead plants give better results.

Table 1 shows a summary of the beneficial effect of certain tillage practices on the presence of living organisms.

PERFORMANCE OF THE SOIL FAUNA IN DIFFERENT ECOSYSTEMS

The soil fauna varies according to the climate and the conditions under which it is exploited depending on the type of production (Andren and Lagerlof 1983; Lee 1983).

Hulugalle and Ndi (1993) studied the performance of termites (Microtermes, Isoptera) and results demonstrated that the populations decreased, in the following order: secondary forests < natural savannahs < crop production

Rombke and Verhaagh (1992) compared the earthworm biocenosis in virgin forests and pasture soils. These authors claimed that earthworms in pastures decreased to approximately one half of that found in the forest. Similar results were observed by Lavelle (1983) in tropical

TABLE 2. Earthworm biomass and abundance in different soil exploitation systems

Systems	Country	Abundance, No/m^2	Biomass g/m^2	Reference
Nursery	Holland	300-500	75-122	Lee (1983)
Wheat	South of Australia	20-25	2-2.5	Lee (1983)
Fallow fields	South of Australia	210-460	16-76	Lee (1983)
Tropical forest	México	132	10.7	Lavelle and Kohlmann (1984)
Tropical forest	Perú	120	11.9	Lavelle and Pashanasi (1989)
Forest of savannah	New South Wales	13.8	10.2	Lee (1983)
Artificial pasture	South of Australia	460-625	62-78	Lee (1983)
Artificial pasture	New Zelanda	740-1240	140-323	Lee (1983)
Grassland	México	620	35.8	Lavelle et al (1981)
Grassland	Perú	474	78	Lavelle and Pashanasi (1989)
Grassland	México	93-740	-	Fragoso and Lavelle (1992)
Native pasture	South Africa	74	96	Lee ((1983)

savannahs. These changes depend on the type of system and are associated with the human impact (Janati Idrisi 1988).

Earthworm population (table 2) ranges between 460-1240 per m^2 and their biomass between 78-323 g/m^2 in grassland systems of different countries, while under systems of wheat production, the populations considerably decrease to 20-25 per m^2, with a biomass of 2-2.5 g/m^2, while in tropical forest conditions averages of 120-132 worms/m^2 and 10-11g/m^2 of biomass are found.

Table 3 shows termite performance in different regions and soil exploitation systems

APPLICATION OF CHEMICALS AND FIRE

Voisin (1962) said: 'Manure is a wonderful tool when it is correctly applied, but a great danger when it is improperly used.'

Chemical fertilizers are substances which have been synthesized to supply nutrients (essential elements) to the soil and the large majority, with some excep-

TABLE 3. Termite abundance and biomass (earth termite) in different exploitation soil systems (after Lee 1983)

System	Country	Abundance, Number of termites/m^2	Biomass, g/m^2
Tropical savannah (semi-arid)	Senegal	229	1.0
Tropical savannah	Nigeria	4400	11.1
Grassland	Nigeria	2010	2.8
Maize (8-28 years)	Nigeria	6825	18.9
Forest stream	Zaire	100	11.0
Tropical forest	Trinidad	4450	-

tions, leave no actually toxic residues, neither in the soil nor in the plant, but they can damage the seeds, rootlets and microbial population, due to their secondary effects: acidity, alkalinity or salinity. These effects are local and temporary and are not greatly harmful when applied correctly (dosage, location, fractioning, time and way of application) (Pineda 1994).

Fertilizers can limit soil life by decreasing the microbial populations and those of the meso and macrofauna on supplying nutrients to the soil, although there are references such as those of King and Hutchinson (1980) and Cambell et al (1995) who found positive effects of fertilization on soil organisms.

Fumigation, using methyl bromate, eliminates the spores of the soil mycorrhizas, while benomyl inhibits colonization. In general, systemic fungicides decrease mycorrhiza colonization, although they have variable effect. There are products that even favour mycorrhiza sporulation (Siqueira and Franco 1988). These authors state that there are many studies on the survival of the rhizobium to fungicide and herbicide applications, but the variability of the results is given by the ecological conditions. There is also variation of the rhizobium performance depending on the tolerance to different products, making generalization very difficult. However, these authors claim that fungicides are very harmful, followed by herbicides and insecticides. In general, they wain that mercurial products should not be used together with inoculation.

A summary of the damage to the soil fauna due to the use of chemical products is shown in table 4.

Today, there are soil pollution problems with heavy metals world wide and according to Yeates et al (1994), Abdul et al (1995) and Frostegard et al (1996), the pollution of the ecosystem with heavy metals such as Cd, Pb, Hg, Cu, Cr, As and Zn affects all the biological production processes and the nutrient cycle.

According to Yeates et al (1994) pollution levels with Cu, Cr and As in grassland systems are below 10 mg/kg of soil, therefore not affecting the biological activity. However, this is not so when pollution levels increase from 400 to 800 mg/kg of soil.

TABLE 4. Negative effect of certain chemicals on soil fauna

Type of products	Damage to the soil fauna	Country	Reference
Pesticides	Microorganisms	Brazil	Siqueira and Franco (1988)
	Coleopterous	Argentina	Marasas et al (1995)
Herbicides	Arthropods	Japan	Watanabe (1983)
Fertilizers	Microorganisms	UK	Bardgett and Leemans (1995)
Fertilizers	Microorganisms	UK	Bardgett et al (1997)
Insecticides	Arthropods	Finland	Holopainen and Rikala (1995)
Carbofuran	Earthworms	USA	Parmelee et al (1990)
Herbicides	Earthworms	Australia	Pizl (1993)
Herbicides	Earthworms	England	Pizl (1993)
Naphthalene	Arthropods	USA	Ingham et al (1994)

TABLE 5. Negative effect of fire on soil fauna

Microorganisms	Spain	Forturbel et al (1994)
Macrofauna	Thailand	Watanabe and Ruaysoongnern (1984)
Microarthropods	Ivory Coast	Attias 1975
Macrofauna	Colombia	Decaens et al (1994)

On the other hand, it is impossible to estimate the annual extent of fires produced by natural disasters or by man himself. This brings about an annual loss from 100 000 to 200 000 km^2 of tropical forests (Castro 1994) while affecting the environment due to the gases produced and soil degradation.

It takes Nature 2000 years to form 2.5 cm of soil and the areas annually affected by fire and the soil losses are alarming, since the rate of disappearance of the arable layer is much higher than what nature can recover.

Table 5 shows the harmful effect of fire on soil microorganisms.

Forturbel et al (1995) summarized the harmful effects of fire on the soil in the following way:

- It prevents the return of the organic matter and increases its degradation.
- It exposes the soil to erosion
- It promotes soil compactation
- It gives soils water repellent properties, making them drier
- It produces a characteristic plant invasion
- It destroys all the soil fauna

There is however, poor information on the ecological changes in the soil after a fire although it has been claimed that the soil is temporarily sterilized (Forturbel et al 1995).

Reports from the literature are variable, since the assessment of these effects varies depending on fire intensity, climate and the sampling method.

Fire has been widely used for grassland recovery (Padilla et al 1982, Arruda et al 1987, Anderson 1988, Collins and Wallanse 1990 cited by Blair 1997, Holstede et al 1995a and b). But an appropriate use of fire depends on a rational and well directed application (Arruda et al 1987).

Soil temperature after burning varies according to the climatic conditions. Soil humidity and wind are the two most important factors according to studies conducted by Alejo et al (1988) who reported temperatures of 204 and 206°C. Blydenstein (1965) cited by Alejo et al (1988) found 130 and 200°C in Venezuela; Tothill and Shaw (1968) in Australia found temperatures of up to 245°C. Temperature was expected to be higher at lower soil humidity, but humidity was not the only factor since the wind had a greater effect.

Watanabe and Ruaysoongnern (1984) studied the changes occurring in the number and biomass of the soil fauna in different groups. After burning these indicators decreased drastically. The groups with higher populations were: Isoptera, Hymenoptera (mainly Formicidae), Diplopoda and Lepidoptera. According to Ahlgren (1974 cited by Harris et al 1995) the changes produced by fire on the microbial activity in different agroecosystems are very difficult to determine because of the effect of factors such as temperature, rainfall after the fire, type of microorganism and sampling method.

In the Ivory Coast, Athias (1975 cited by Watanabe and Ruaysoongner 1984) determined that in unburnt savannahs the number and biomass of microarthropods were three times higher than in burnt areas. This shows the negative effect of this practice on the soil fauna.

CONCLUSIONS

Biological activity increases with correct soil management and conservation practices, such as minimum tillage, the use of strips with vegetation in ploughed soils and the frequent application of organic matter. Among the management practices soil fauna is stimulated when efficient crop rotation and plant coverage are used. In tropical soils, the use of these management practices is of vital importance for soil conservation and must be carried out efficiently, since sometimes the practices used hasten the destructive process instead of stimulating soil fauna and conservation.

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